Ocean and Coastal Management 172 (2019) 14–29

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

The perception of climate-related coastal risks and environmental changes on the Rangiroa and Tikehau atolls, French Polynesia: The role of sensitive and intellectual drivers

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ARTICLE INFO

Keywords:
Climate change
Coastal risks
French Polynesia
Perception
Perception drivers

ABSTRACT

French coastal policies have recently put greater emphasis on the need to better inform coastal populations about coastal risks in the context of climate change, in particular in French overseas territories that are nationally recognized as hotspots. It is therefore critical to further assess local populations' knowledge and perceptions of climate-related coastal risks. In this respect, we ran a social survey among inhabitants of two atolls of French Polynesia in the Pacific Ocean, using a questionnaire and semi-structured interviews largely based on images of landscapes. The results show that (1) coastal risks are not considered as a danger but only as a problem, and that (2) inhabitants have a very clear perception of the changes that have occurred locally over the last 70 years with respect to weather, climate, corals and beaches. (3) Interviewees generally show some knowledge about the notion of global climate change and its potential local impacts. (4) However, a multiple correspondence analysis distinguishes four groups (the 'informed', 'poorly informed, 'uninformed' and 'distant' groups) separated by age and gender, but also by levels of education and urbanization. The discussion therefore focuses on the most important drivers of climate change perception, showing a disconnection between atolls and generations: rural and older inhabitants present more sensitive mechanisms of risk perception and urban and younger interviewees more intellectual ones. A major challenge consists in bringing these dimensions closer by better integrating, on an intellectual level, local climate-related coastal risks into school programs, and by defining, on a more sensitive level, an ambitious cultural and environmental policy to allow young generations to keep contact with their original living environment. Highlighting the interest of this survey, risk management and adaptation policies now support the reactivation of local knowledge and practices.

1. Introduction

In 2015, less than half of all French people were convinced that climate change is really happening (Boy, 2015). The inhabitants of French Overseas Territories (FOT), however, seem to be more aware of the climate-related risks and flood risk than people living in mainland France (respectively 56% versus 42%, and 37% versus 28%) (Pautard, 2015). Despite this, and according to our own research in the Tuamotu coral archipelago in French Polynesia, less than 5% of the inhabitants name natural risks in general as one of the 'drawbacks' of living on an atoll. Partly for this reason, on several Tuamotu atolls, nationally-driven risk prevention plans (*Plans de Prévention des Risques*) – i.e. institutional tools that describe areas prone to coastal flooding in the future and potentially priority areas for building and the resettlement of people – have not yet been approved because of local opposition to the regulatory constraints. This apparent contradiction raises a fundamental question: is perception of climate-related coastal risks really higher in the FOTs compared to the continental mainland, or is it merely of a different nature?

It is difficult to answer this question for French Polynesia because,

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https://doi.org/10.1016/j.ocecoaman.2019.01.018
Received 27 June 2018; Received in revised form 21 January 2019; Accepted 24 January 2019
Available online 06 February 2019
0964-5691/

to date, very little scientific work has covered the perception of climate change and sea-related risks in this area, especially in the Tuamotu Archipelago (Worliczek, 2013; Canavesio, 2017; Torrente, 2017). The knowledge of perceptions helps understand people's attitudes towards coastal risks policies or towards adaptation to climate change. Therefore, since 2010, French public coastal policies have put greater emphasis on populations and the need to better inform coastal residents about sea-related risks and what is occurring with climate change. For instance, the *National Strategy for the Sea and Coast* (2017) stresses the need to develop 'a marine and maritime knowledge society' as a priority action. In Polynesia, the *French Polynesia Climate Energy Plan* (2015–2020) also recognizes the social drivers of risk and highlights risk perception as critical in supporting local safeguarding plans at municipal level. The Plan also insists on training for elected representatives and agents and on raising inhabitants' awareness about climate change-related threats (Action no.21). Against this background, scientific research can help further capture how populations perceive, interpret and understand local coastal risks in the context of global climate change. These three elements (sensitive perception, interpretation and knowledge) are what make up the notion of 'perception' in this paper.

However, while a substantial body of scientific literature examines perceptions of climate change and natural hazards, in terms of both the drivers of perceptions and the implications on societies' exposure and vulnerability to risk, few studies are available on atoll contexts (Mortreux and Barnett, 2009; Longépée, 2014; Lazrus, 2015). Moreover, while perception of environmental changes and climate change-related risks are usually studied for a given restricted period of time, usually the present-day (Worliczek, 2013; Longépée, 2014; Torrente, 2017), this paper looks at the perceived changes and risks that occurred over several decades. To help fill the lack of studies regarding perceptions of climate change and natural hazards on atolls in general and in French Polynesia in particular, this paper analyses the perception of decadal environmental changes and climate-related coastal risks in the Tuamotu Archipelago, based on a survey among 270 inhabitants of the Rangiroa and Tikehau atolls. It discusses what drives perception of climate change in general and on the local level, as well as the implications for the policy on adapting to climate change.

After describing the context, objectives and methods of our study, the paper examines how the inhabitants of these two atolls perceive current sea-related risks, multi-decadal environmental changes, from the past to the future, and climate change in general, and what are the drivers of those perceptions. It then discusses the general perceptions and their drivers, but also the implications for French Polynesian climate change adaptation policies.

2. Objectives, materials and methods

2.1. The physical and human context of the study area

Located in the Central Pacific Ocean (longitude 134–136°, latitude 14°–24°), the Tuamotu Archipelago is one of the five archipelagoes of French Polynesia. It is 1800 km long and 600 km wide, composed of 76 coral atolls and had a total population of 15,346 inhabitants in 2017 (according to Institut de la Statistique de Polynésie Française (ISPF), 2017 census). More than 21% of the population is located on the atoll islands of Rangiroa and Tikehau, mostly in the former. Since the 1970s, scientific investigations on socio-ecological issues have primarily focused on Rangiroa (Ottino, 1972; Worliczek, 2013; Prenveille, 2014; Ranché et al., 2016; Duvat et al., 2017), although since the 1980s, some studies have also been conducted on Tikehau (Anonyme, 1985; Anonyme, 1986; Caillaud, 1987; Rubia, 2014; Ranché et al., 2016; Duvat et al., 2017). Rangiroa atoll (Fig. 1) measures 87 km across and 37 km wide, and is the largest atoll in the Tuamotu Archipelago. It has two passes to the north – Avatoru and Tiputa – next to which the two main villages, of the same name, are located. In the 1980s, the village of Avatoru (Fig. 1a) began to spread rapidly eastwards, reaching the hamlet of Ohotu and the Tiputa pass (Fig. 1b). The islands of Avatoru (1.3 km^2) and Tiputa to the east (0.7 km^2) are typical of *motu* (reef islet) morphology (Stoddart, 1969) with, from the ocean to the lagoon, a succession of three main features: a detrital strip of sand and coral debris culminating at a height of 5 m, a relatively flat inland area, which is marshy in places, and a low sandy coast lying below an altitude of 2 m. The two islands are typically elongated but rather narrow, measuring between 270 and 570 m across at Tiputa, for example. In the neighboring atoll of Tikehau (Figure 1c), 15 km west of Rangiroa, the southern island of Tuherahera (2.5 km^2, 3.5 km long and between 450 m and 900 m wide) is home to the large majority of the atoll's population. It also slopes downwards towards the coastal lagoon area and to some inland marshes. These marshes have been partially filled in to create an airstrip. The reef ring is only broken by a single pass to the west. Tuherahera's topography does not rise more than a few meters high, its highest part found to the south (maximum of 6–8 m).

From the second half of the 19th century, the Archipelago witnessed development in copra farming (coconut palms), driven by French settlers, with two main consequences (Ottino, 1972; Ravault, 1980). Firstly, the emergence and development of a trade-based and monetary economy with, as copra was exported, the import of new foodstuffs. Secondly, the sedentarization of communities in villages located near the passes to facilitate external trade, with Rangiroa serving as a hub for trade with Tahiti. Before that, the islands' traditional form of occupation comprised dispersed and itinerant settlements that made use of the resources found on the different islands. The crisis on the copra market in the mid-20th century triggered a fall in living standards among Tuamotu's inhabitants and a rural exodus from outer and copra-farming atolls to the island of Tahiti, the economic heart of French Polynesia. In the Archipelago economic alternatives were then developed in the 1980s, including pearl cultivation which also underwent a severe crisis in the 2000s, and tourism, the effects of which very quickly stagnated. Putting its demographic evolution aside, the Rangiroa atoll reflects this general history. While it was the largest copra producer in French Polynesia in the mid-20th century, production has since dropped off and fish exports to Tahiti have increased. At the same time, the atoll has gained a worldwide reputation among scuba divers and developed public infrastructures (airport, health dispensary and a middle-high school) as both a consequence and a cause of a population increase. In 2017, the atoll had a population of 2709 (ISPF, 2017 census), which is 2.3 times higher than in 1983. The hamlet of Avatoru (Fig. 1a) is the most populated and was the main focus of the demographic boom that the atoll experienced from the late 1950s. Consistent with this, the number of public and residential buildings in Avatoru has also significantly increased, going up from 200 to 1082 between 1981 and 2013 (Ranché et al., 2016). On the atoll, Ohotu (Fig. 1b) can also be considered as semi-urban whereas Tiputa, which lies across the pass and is only accessible by boat, is more rural (Fig. 1b). Likewise, on Tikehau, the creation of coconut groves has led to gradual sedentarization on the island of Tuherahera. In recent times, Tikehau has also seen significant population growth, although less than on Rangiroa: in Tuherahera the population rose from 279 to 560 between 1983 and 2017 (ISPF, 2017 census), and the number of buildings from 134 to 337 between 1981 and 2014 (Ranché et al., 2016). However, the atoll of Tikehau remains more rural than that of Rangiroa, with 4.8 times fewer inhabitants and 3.2 times fewer buildings. Copra production is also declining on Tikehau. The opening of an airport in 1977 spurred tourist development with guest houses and an international hotel complex that provides a number of jobs. However, fishing remains one of the main sources of income (Kronen et al., 2009) and, as is the case on Rangiroa, many people need to have more than one job. Given the above, this study considers Rangiroa as a whole as more urban than Tikehau, although within Rangiroa, the hamlet of Tiputa is less urbanized than the Avotoru-Ohotu ensemble (Fig. 1). Consequently, this study identifies three inhabited areas along an urban-to-rural gradient, respectively

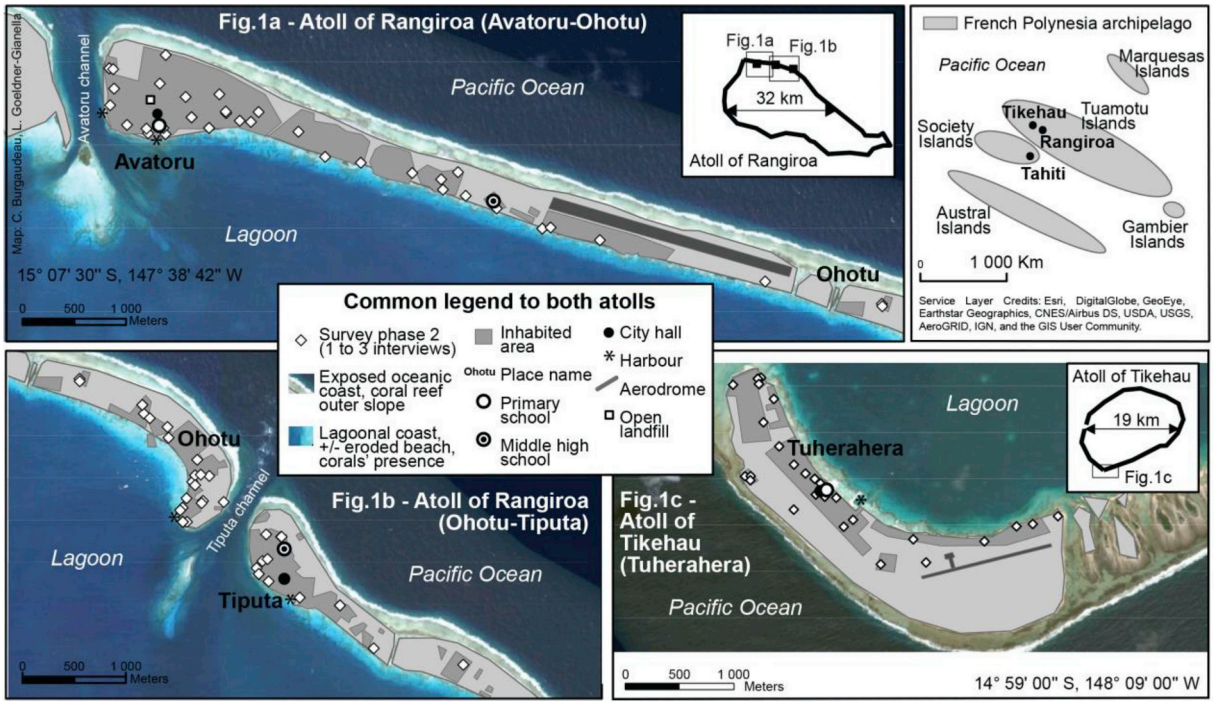

Fig. 1. Maps of the atolls of Rangiroa and Tikehau, Tuamotu Archipelago in French Polynesia. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Avatoru-Ohotu, (Fig. 1a and b), Tiputa (1b) and Tuherahera (1c).

Given their physical characteristics, especially their low altitude, small size and their exposure to distant and storm-induced swells, Rangiroa and Tikehau atolls are strongly concerned by two major coastal risks: flooding and erosion. Several flood events have occurred over the past few decades, often triggered by cyclones, e.g. at the beginning of the 20th century and in 1983 and 2010, or linked to the southern swell as in 1996. Around a third of the Rangiroa atoll was submerged during two cyclones in 1983, with water reaching 60 cm deep in the village of Avatoru during tropical cyclone Orama. Destroyed by a cyclone in the early 20th century, the village of Tuherahera was slightly displaced. After that, half the surface area of the Tikehau atoll was submerged during tropical cycle Veena in 1983, with water 60 cm deep in the village. The village island of Tuherahera was 90% submerged by the southern swell in 1996, when water reached a depth of 1 m (Prenveille, 2014; Rubia, 2014). Both atolls are also subject to erosion (Fig. 2) and contraction processes. Duvat et al. (2017) describe the erosion processes affecting the coastline and the contraction of three of the *motu* of Rangiroa (out of the eight studied between 1966 and 2013), and of seven *motu* of Tikehau (out of the 14 studied between 1962 and 2014), plus two *motu* that have totally disappeared. However, the same authors also point to the stabilization/expansion of certain *motu* and an advancing coastline for four out of eight *motu* in Rangiroa and two out of fourteen *motu* in Tikehau. Erosion is not therefore a widespread phenomenon. However, on these atolls as elsewhere, regardless of future – and at this point uncertain – evolution in the frequency or intensity of cyclones and distant swells (Nurse et al., 2014; Wong et al., 2014) in places where the coastline will not naturally rise, we can expect more extensive coastal flooding as sea levels rise (Seneviratne et al., 2012; Nurse et al., 2014; Wong et al., 2014; McLean and Kench, 2015). Since the 1950s, the rate at which the sea level has risen in the Pacific basin has varied between +2.5 and + 5.5 mm/year with, for example, +3 mm/year at Papeete (Tahiti) (Becker et al., 2012). It is estimated that by the end of the century, this rate will increase more than the global average (Church et al., 2013). Finally, other environmental changes inherent to climate change need to be taken into consideration, although they remain relatively unexplored on these two atolls at the present time. The acidification and warming of the ocean will affect the resilience and natural ability of ecosystems such as coral reefs to adapt (Gattuso et al., 2015; Hughes et al., 2017). These pressures will limit the corals' capacity to grow vertically to follow rising sea levels (Perry and Morgan, 2017; Yates et al., 2017) and to continue to fulfil their role in attenuating waves and providing food. Coral is also ravaged by strong swells and cyclones. For example, the living coral cover on the outer reef slope of the Tikehau atoll regressed significantly immediately after the passage of the southern swell in 1996 and cyclones Veli and Oli in 1998 and 2010 (Duvat et al., 2017). Coral also suffers from bleaching (Fig. 2). Scientists consider that

Fig. 2. Photographs of environmental changes visible in spring 2017 on Rangiroa (2a. coral bleaching, 2b. beach erosion, 2c. hard defense measures). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

bleaching markedly affected the lagoons in the atolls of Rangiroa and Tikehau and the outer reef slopes in 1991, 1994, 1998 and 2016.

In addition to these environmental factors, anthropogenic aspects also considerably influence current and future risk levels. Until the 18th century, the population was concentrated on the most accessible *motu*-, also the highest and best endowed in fresh water. Houses were also built on a coral platform reaching 1.20 m high, and sometimes surrounded by walls to limit the impacts of coastal flooding (Ministère du logement, de l'aménagement, de l'urbanisme et du numérique, 2017). However, Ranché et al. (2016) showed that, since the late 1980s, there has been a strong increase in inhabitants' exposure to this risk, for three main reasons. Firstly, a greater density of homes and public buildings in naturally exposed areas is the result of the demographic pressure mentioned above. Secondly, in early 2015, only 52% of dwellings in Rangiroa and Tikehau were raised by at least 50 cm above ground level, and 23% by at least 20 cm. Finally, the inhabitants of Rangiroa and Tikehau have recently introduced a number of inappropriate sea defense measures, ranging from concrete sea walls (Fig. 2) to planting in vulnerable areas, although this has mainly be done to fight local erosion and not as a flood defense. Risk levels on these two atolls are therefore relatively high at present and will certainly increase in the near future. As such, the political authorities currently insist on the importance of speeding up the natural risk prevention plan drafting process and on the need to implement a plan to construct more cyclone shelters in French Polynesia (Arnell et al., 2018: Recommendations no.3 and 5).

2.2. Insights from the scientific literature on climate-related risk perception

From developed nations to small islands, risk perception helps shape the attitudes of the authorities and of people towards extreme events and/or slow-onset changes. There is substantial scientific literature examining risk perceptions in relation to climate change and sea-related hazards in terms of both the drivers of perceptions and the implications on societies' exposure and vulnerability to risk. However, to date, very few studies have addressed risk perceptions in atoll contexts (Mortreux and Barnett, 2009; Longépée, 2014; Lazrus, 2015), or focused specifically on French Polynesia (Worliczek, 2013; Canavesio, 2017; Torrente, 2017). Nonetheless, some general considerations on risk perception bring useful insights to our study, especially in terms of communities' relationships to the environment and the consideration given to climate change-related risks.

Generally, studies describe risk perception as the result of intertwined predictors such as 'gender, political party identification, cause-knowledge, impact-knowledge, response-knowledge, holistic effects, personal experience with extreme weather events, [social norms] and biospheric value orientations' (Van der Linden, 2015; see also Bord et al., 2000; Kellens et al., 2011; Carlton and Jacobson, 2013; Lujala et al., 2015; Lee et al., 2015; Weber, 2016). The influence of the distance from the sea is also discussed (Lujala et al., 2015; Milfont et al., 2014; O'Neill et al., 2016). Due to its multi-factorial, context-specific nature and to its influence on local policy, decision and action in the face of climate change (e.g. Terpstra, 2011; Van der Linden, 2015), risk perception is acknowledged to be a complex anthropogenic driver of communities' exposure and vulnerability to climate-related changes. The nature of perception predictors is still the subject of debate. Studying high-income countries contexts, for example, Shi et al. show that 'general scientific knowledge [is not] a robust predictor of perceived climate change risks [and that] instead, risk perceptions [are] more heavily influenced by cultural world views' (2016, p. 759). Our study will help identify the drivers of perception of risks and climate change in these atolls by looking at the respective importance of sociodemographic and conventional educational factors, as well as those known to influence relationships with the environment, such as location and distance from the sea (Brody et al., 2004; Glatron and Beck, 2008; Lujala et al., 2015; Milfont et al., 2014; O'Neill et al., 2016; MEEM, 2017; Coquet et al., 2018), and the relationship with or attitude towards the environment (Carlton and Jacobson, 2013). The real influence of risk perception on exposure and vulnerability, especially when introducing the issue of climate change, is also debated. There is, however, a relative lack of studies on the variability of risk perception's influence in diverse geographical and human contexts (e.g. Terpstra, 2011; Van der Linden, 2015; Elrick-Barr et al., 2017), and almost no information on it on Polynesian atolls (Bambridge and Latouche, 2017; Torrente, 2017).

The above illustrates the attention paid by scientific studies not only to the influence of socio-economic and educational factors, but also to local communities' relationships with their living environment. In this respect, the Traditional Ecological Knowledge (TEK) approach is key. Since TEK is basically rooted in the observation of the environment (moon, waves, winds, animal behavior, etc.), it reflects a more general concern about the sense of the environment in contemporary societies, which is not exclusive to remote, rural and developing communities. Recent literature reaffirms that TEK makes a profound contribution to the way people recognize and respond to environmental risks (Bridges and McClatchey, 2009; Lefale, 2010; Leonard et al., 2013; Lazrus, 2015; Ford et al., 2016; Morrison, 2017; Nunn et al., 2017). Using examples of small islands in South-East Asia, Hiwasaki et al. (2015) describe TEK as being an integral part of social-ecological processes structuring cultural traditions and activities. These authors hence highlight the contribution of TEK as both a root and an outcome of customary resource management systems aimed at regulating the use of resources and the protection of critical ecosystems, at structuring the relationships between people and authorities, and at framing and maintaining a sense of the environment in the community. In turn, the authors suggest that this may allow local communities to predict and prepare for onset events and anticipate the consequences of gradual changes, such as the rising sea level. For example, in some rural Pacific atolls, traditional food preservation and storage methods (e.g. storing germinated coconuts or drying fish) still play a role in anticipating disruptions in natural resource availability (Campbell, 2015; Lazrus, 2015). All of this suggests that a weakening of the relationship with the environment and the related social processes will increase populations' exposure and vulnerability to the impacts of rising sea levels (Nakashima et al., 2012), especially in remote atoll contexts. The literature notably points out that modern, externally-driven socio-economic dynamics such as the introduction of imported food diminish the cultural importance of TEK-based practices and diets locally, and introduce dependency on monetization and external markets (Hay, 2013; Campbell, 2015). This conclusion can be extended to risk perception, as described for the rural Nanumea Atoll where Lazrus (2015) shows that the progressive loss of cultural relationships with local environmental dynamics increased the community's exposure and vulnerability to environmental disruptions and gradual changes, notably through unsustainable livelihood practices and little consideration for natural hazards. Here, we will look at whether, in the specific context of French Polynesia, at the interface between modernity and tradition, TEK has been maintained or has regressed, and the consequences on the perception of risks and climate change.

2.3. Survey methods

To analyze the perception of decadal environmental changes, coastal risks and climate change on the Rangiroa and Tikehau atolls, and understand what drives that perception, we ran a geo-sociological survey. Our survey was run over two phases to improve the quality and accuracy of the results obtained. The first phase was a 'pilot survey' (phase 1) associated with the REOMERS research program on sea-related risks. Two interviewers questioned 145 inhabitants aged 18 and over face-to-face on both atolls, using a structured questionnaire administered between February and March 2014 (Rubia, 2014; Prenveille, 2014). We thought that the highly interesting results from the REOMERS program could be numerically increased and, above all,

Table 1
List of questions in phases 1 and 2 of the survey analyzed in this paper (excluding questions on the interviewees' socio-demographic profile).

	SURVEY PHASE 1	SURVEY PHASE 2
SEA-RELATED RISKS		Select five cards illustrating preoccupying problems for your atoll, and then rank them
	Have you ever experienced a major cyclone causing damage in your neighborhood?	- What dangers could come from the sea or be sea-related? - Which is more dangerous for the atoll? … the sea, ahead of wind? … tsunamis, ahead of cyclones? … coastal erosion, ahead of coastal flooding? - On the atoll, where are the dwellings that are the best protected from the sea? - On the atoll, where are the dwellings that will be the best protected from the sea in the future?
	Do you think that you face risks by living here?	- Are there any drawbacks to living on this atoll? - Do you keep yourself regularly informed of weather events that could affect this atoll?
ENVIRONMENTAL CHANGES	Near your house, are the beaches losing sand?	- What period does each image call to mind? (for the periods before 1950, 1950–2000, today) - Have you observed significant changes to the landscape on your atoll since you've lived here?
CLIMATE CHANGE	Have you heard a lot about climate change?	- Have you heard about climate change? - What does 'climate change' mean to you?
	- To your mind, will cyclone intensity change in the future? - To your mind, will the strength of waves change in the future? - To your mind, is there a risk that erosion will increase in the future? - To your mind, will coral health deteriorate in the future? - Could the rising sea level render parts of your village inhabitable in 60–70 years?	- What period does each image call to mind? (for 2050 and 2100) - Is your atoll one of the sites in the world that could be affected by climate change in the future?
		Would you agree to move in the future because of the effects of climate change? Do you pass on your environmental knowledge to children?

enriched to meet the requirements of the current STORISK research program, which also examines sea-related risks although over a longer period, in the context of climate change. A change was made to the survey protocol (to use an interview format rather than a questionnaire format) between phases 1 and 2. Thus this second phase involved more in-depth, semi-structured interviews lasting between 45 min and 2 h. In May–June 2016 and April 2017, four interviewers questioned 125 people aged 18 and over living on Rangiroa and Tikehau. This change of protocol, to deliberately cover less targeted themes than in phase 1 (Table 1), meant the interviewees were able to express themselves more freely and for longer than with the questionnaire format, and to explain their replies. For example, the interviewees were asked about the dangers coming from the sea (phase 2) rather than specific cyclonic episodes (phase 1), about changes to the landscape or climate change in general (phase 2) rather than specific changes to be expected in the future (phase 1), or about the benefits and drawbacks of living on an atoll (phase 2) rather than using the targeted notion of risk (Table 1). In phase 2, asking interviewees to think about general changes to the landscape and using freely selected or sited images (Table 1) – which we will explain below – widened the thematic scope and enabled greater freedom in the responses. It turned the highly targeted pilot survey (phase 1) into a broader and more open survey (phase 2).

Over the two phases, 13.2% of the population (aged 20 and over, ISPF, 2012 census) of Rangiroa and Tikehau were interviewed. In both phases, the interviewees were selected at random in various places (at home, outside, in public areas or in the workplace) but also, for a very small number (< 5% of the surveyed people), on recommendation as they were believed to 'have many things to tell'. Gradually, however, interviewers sought a variety of geographic contexts, age groups, genders and occupations to reflect the local population's average statistical profile as closely as possible.

We also took into account the fact that the local population may have difficulties understanding French, the language in which the interviews were conducted. Although the population census indicates that 93% of the benchmark population aged over 20 'understands, reads, writes and speaks French' (ISPF, 2012 census), the percentage is lower in rural areas and among older people: only 87% of the inhabitants of the rural atoll of Tikehau master the French language. Among people aged 60 and over, only 76% living on Rangiroa and 59% living on Tikehau master the language. The French political authorities currently recommend that documents on territorial risks are distributed in French and local languages (Recommendation no.18, Arnell et al., 2018). In our survey, to overcome linguistic and lexical difficulties, images were used in three instances during phase 2. 1) The interviewees were asked to select and rank five cards from twenty images illustrating various kinds of problem that could affect the atoll and deemed preoccupying to a certain degree by the interviewees (Table 3). The potential problems illustrated in the images were selected based on knowledge of the two atolls acquired during previous missions and on scientific literature concerning these sectors (Worliczek, 2013; Ranché et al., 2016; Canavesio, 2017; Torrente, 2017). 2) A second image-based technique asked people to comment on three drawings produced prior to the survey by teenagers from the Rangiroa middle high-school (11–12 to 14–15 years old). In fact, as part of the STORISK program, a survey was also carried out with this institution, which takes in teenagers from this atoll and eleven surrounding atolls in Western Tuamotu. Hence, 289 11-15-year-olds were asked to spend 1 h producing 'a drawing of their atoll's landscape' and, a second drawing to 'imagine what it would look like in 40 years' time'. Three of these drawings were selected by the researchers to provide a diverse view of perceived future environmental changes in the atolls studied. One of the drawings showed the atoll's coastline subject to more intense urbanization and tourism; the second showed water pollution, marine biodiversity loss and the atoll retreating under the effects of rising sea levels; the third illustrated climate change with the complete submergence of an atoll as sea level rises. The interviewees were asked to say, for each of the three selected drawings, whether or not the change illustrated by the teenager was possible on their atoll by 2050.3) The third image-based technique asked the interviewees to place images of landscapes on a timeline spanning more than 150 years and split into five 'key periods' of

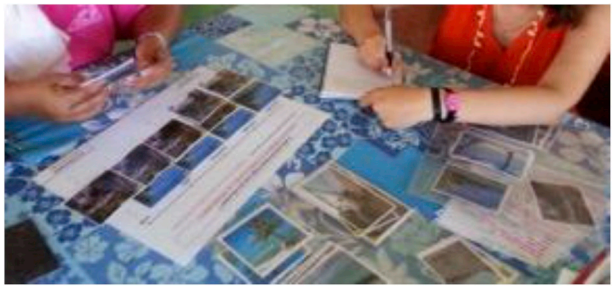

Fig. 3. Timeline on which the interviewees were asked to position images. (STORISK survey, Phase 2). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

varying length, from the past to the future: before 1950, 1950 to 2000, present day, 2050 and 2100 (Fig. 3). As one interviewee commented, 'the timeline shows me, my parents and my grandparents'. The set of images was made up of four themed series, examined one after the other with the interviewee. The series presenting the atoll's economic activities comprised six cards (fishing, fisheries, pearl cultivation, tourism, cruise ships, and copra/monoi), while the series on weather/climate conditions was made up of five cards (usual weather, flooding after rain, strong swell, cyclones and flooding by the sea). The series on the state of the beaches contained five cards (healthy beach, eroded beach, beach with sand extracted, beach with groynes, and a beach subject to a rising sea level), and the series on corals comprised three cards: healthy coral, coral bleaching and snorkeling activities. There were five copies of each card to be placed, if desired, on the five key periods on the timeline. The interviewees had to place the cards in response to a simple question: *'What period does each image call to mind?'*, given in French and in Tahitian (Fig. 3).

This use of images, based on three different methods, was essentially intended to overcome linguistic and lexical difficulties. However, it brought other benefits: the 'photo elicitation interview' (Harper, 2002) helps with expression and the recognition of elements, as Hatt summarizes when he says that the photograph 'triggers ideas' (2010). In addition, using photographs of landscapes, instead of a real landscape that would not otherwise be visible to the interviewees during a survey, gives similar results in terms of landscape choices (Le Lay et al., 2012). The use of photographs also enables comparisons over time and quantitative analyses, and the image facilitates dialogue with the interviewer. However, despite their usefulness, we must not minimize the difficulties or biases that the images can produce (Collier, 1967; Harper, 2002; Hatt, 2010; Le Lay et al., 2012). For example, more time is required for the survey because it is first necessary to go photographing into the field. It is also necessary to think about framing and the content of the landscapes photographed, and to bear in mind that the photographer's subjectivity is involved. Potentially complex landscapes featuring various elements may be presented, even though the interviewer is interested in only one element. The photographs are also affected by the seasons and the images may be selected by interviewees for aesthetic rather than rational reasons. We were however convinced of the importance of using images in the context of Tuamotu, and therefore attempted to limit, if not counter, most of these biases. Hence, for the first method where the interviewees were asked to select and rank five cards, to prevent any difficulties in interpreting the 20 images used, each card was also accompanied by a key word or expression summarizing it, written in French and Tahitian. In the second method using the teenagers' drawings, we tried to minimize biases in two ways: firstly, the teenagers all described their drawings orally to prevent any bias in the adults' (both the scientists and the interviewees) interpretation and secondly, the three drawings selected were systematically described by the interviewers for the interviewees before the latter were asked, for each picture, whether the change illustrated by the teenager was possible on their atoll by 2050. Finally, for the timeline method where the interviewees were asked to place images on the line, we made sure that we selected photos that were as simple and as representative as possible, only expressing one specific notion related to a series (for example, the notion of 'erosion' in the 'beach' series, or the notion of 'bleaching' in the 'corals' series). Moreover, because it was easier to get people thinking with photographs of landscapes where the condition could be clearly seen (eroded beach, bleached corals, etc.), than with photographs that represented a process (such as the rising sea level) or physical impacts (such as a flood, where you cannot tell from the image whether it was caused by rainfall or the sea), we minimized interpretation biases by systematically orally describing the few potentially ambiguous images to the interviewees, so that they could process them properly with regard to the timeline.

For data interpretation, statistical analysis was carried out using flat sorting and crossed tabulations. A Chi-square analysis was used to test for statistical significance between social variables and the answers obtained, with a p-value = 0.05. We also carried out a multiple correspondence analysis (MCA): this form of statistical analysis gives a representation of the answers provided over two dimensions in our study. Graphically, each dimension is placed at the centroid of the individuals possessing that dimension. It is thus possible to visually identify closeness between the dimensions of several variables: for example, on Fig. 5, the '31–50 years old' dimension of the Age variable is close to the 'sea-related occupation' dimension of the Occupation variable. In this way, an MCA can be used to determine typologies of individuals according to the adjacencies that are identified, although there is a continuum between profiles. For the MCA that we ran, we used nine socio-demographic characteristics and personal characteristics on the people interviewed. Two questions were included in the MCA as descriptive variables. The first was used to determine the level of theoretical knowledge on climate change in four terms: knows the causes of climate change; knows its manifestations; low level or lack of knowledge; associates climate change with catastrophism, fear or uncertainty. The second, more specific question referred to the fact that the atoll concerned by the survey might be affected by climate change in the future (the seven terms of the responses are shown in Fig. 4).

3. Results

3.1. Characteristics of the people interviewed in phases 1 and 2

The average profile of the local population aged 20 and over was summarized for both atolls together, using data from the last census fully available[1] for French Polynesia, conducted in 2012 (Table 2). Thanks to the gradual adjustment of the type of people interviewed during phase 2, the profile of the population questioned is quite close to the benchmark population (Table 2) as concerns the breakdown of gender, age, origin and education level: 54% of the interviewees were men, compared to 51% of men in the benchmark population; respectively 15% and 13% aged over 60; 84% and 86% of Polynesian origin; 17% and 21% of people had a bachelor level or more. However, a higher percentage of people were questioned on the Tikehau atoll in phase 2 (27%, compared to 18% in the benchmark population), to enable statistical processing. In addition, in phase 2, we interviewed fewer low-educated people than there are officially (46% versus 63%), no doubt due to the fact it was difficult to convince them to take part in the survey.

We can also see that phases 1 and 2 covered quite similar population samples as concerns variables that are not part of the official census: geographic distribution within the atoll (they live respectively on the ocean side, in the central part of the islands or on the edge of the lagoon), their origin (84% Polynesians and 16% non-Polynesians in each

[1] Data from the census conducted in summer 2017 were not available in 2018 at the time of writing.

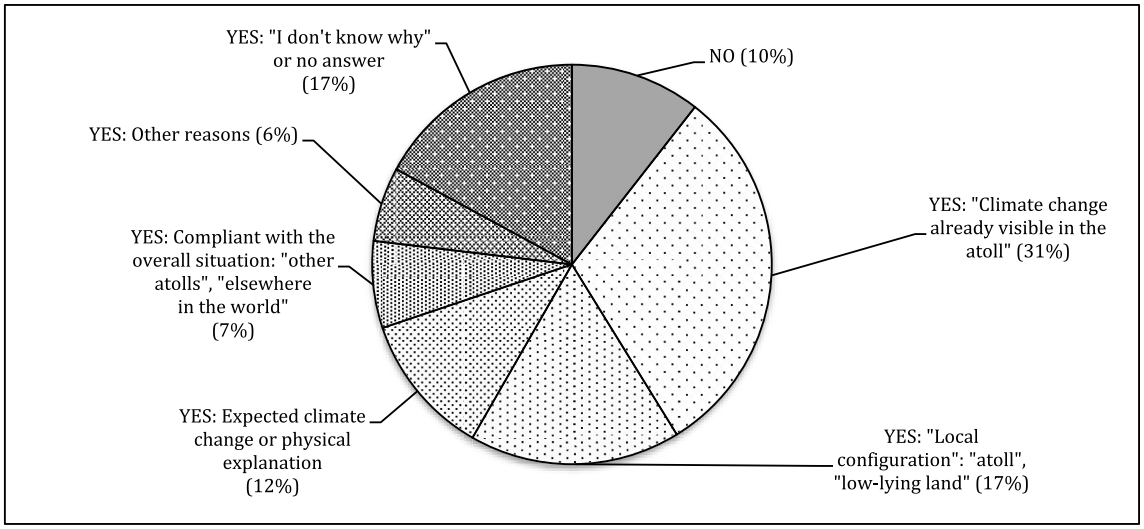

Fig. 4. Answers to the question: 'Could your atoll be affected by climate change in the future?' and explanations from people having answered 'yes' (n = 95, as in Fig. 5).

case), their occupation (a large majority of occupations not related to the sea in each case) and the date on which they settled permanently on the atoll (respectively 22% and 23% less than 10 years ago, and 60% and 57% more than 20 years ago).

In the following results, we set out the responses given by individuals according to theme, looking at what was said about sea-related risks, environmental changes in general and then climate change, before analyzing whether or not perception of these risks and changes is influenced by specific drivers.

3.2. Sea-related risks: more of a 'problem' than a 'danger'

In phase 2, we began the survey by asking the interviewees to select five cards illustrating 'preoccupying problems for their atoll'. The most frequently selected card, if we take all the cards together, from first to fifth choice (Table 3), was an open-air pile of waste (more than 70% of replies). This is a concern because waste is deposited in open landfill sites on the atolls since it is too costly to transport it to Tahiti. The themes of sea-related risks and climate change then appear most frequently selected in the seven cards, just after the waste issue, with high percentages for 'rising sea levels' and 'cyclones' (more than 40% of

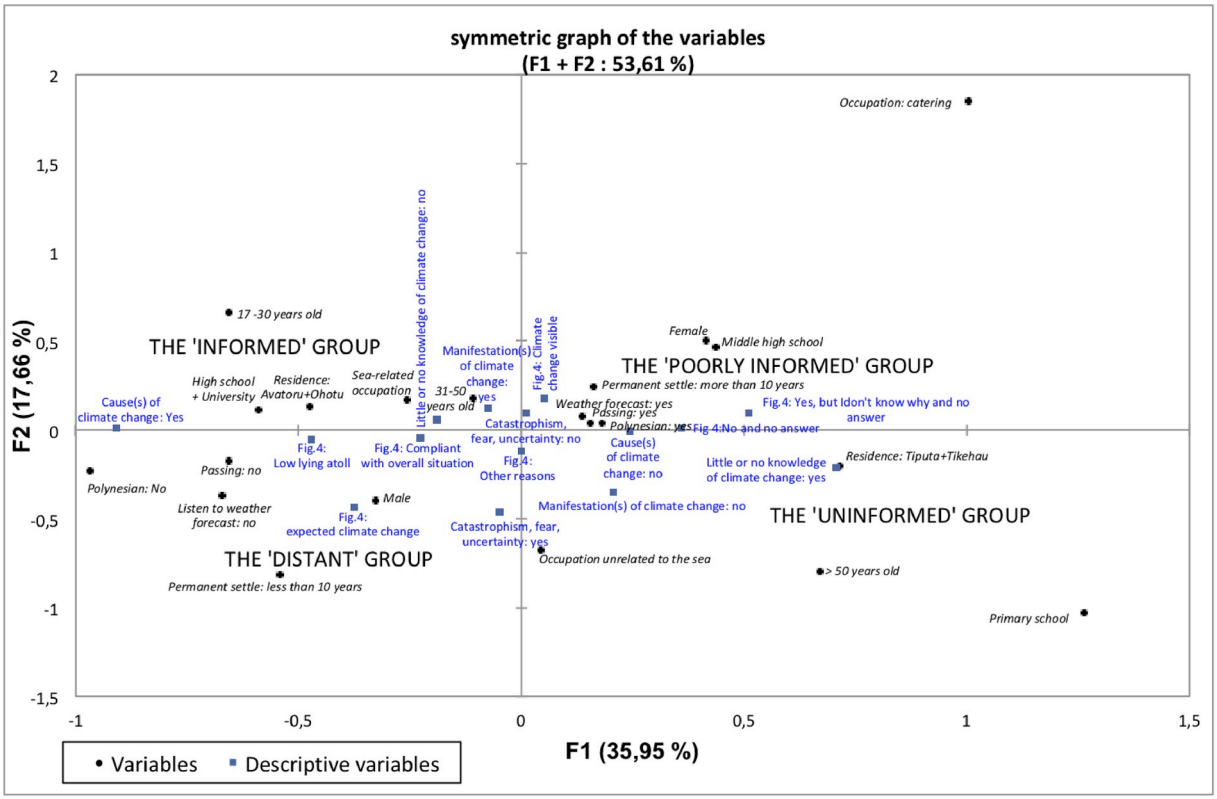

Fig. 5. Four distinct groups of residents can be distinguished on the basis of the MCA (n = 95). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Characteristics of the people interviewed in phases 1 and 2 compared to the benchmark population of Rangiroa and Tikehau (Institut de la Statistique de Polynésie française).

			PHASE 1 2014 (n = 145) (in %)	PHASE 2 2016–2017 (n = 125) (in %)	2012 Census for the Tikehau and Rangiroa population, aged 20 and more (ISPF) (in %)
GENDER	Male		59	54	51
	Female		41	46	49
AGE	18–39		49	37	49
	40–59		38	48	38
	60 and over		13	15	13
LOCATION	Rangiroa	Avatoru	58	37	82
		Tiputa		15	
		Ohotu		21	
	Tikehau		42	27	18
LOCATION OF THEIR HOME	On the ocean side		10	11	/
	On the lagoon side		50	45	
	In the middle of the atoll		40	44	
ORIGIN	Polynesian		84	84	86
	Other		16	16	14
EDUCATION LEVEL	Primary school		/	18	63 (Middle high-school exam)
	Middle high-school (11–14 years old)			28	
	High school (15–17 years old)			37	16 (BEP-CAP)
	Bachelor level (18 years old) and over (university)			17	21
OCCUPATION	Not related to the sea		75	56	/
	Partly related to the sea: tourism		5	20	
	Partly related to the sea: craft industry: pearls, shells, etc.		3	13	
	Related to the sea: fishing, navigation, etc.		17	11	
LEISURE	Fishing (of all types)		35	23	/
	Water sports (bathing included)		29	10	
	Diving and underwater hunting		10	30	
	Shells		3	8	
	Other leisure pursuits (related or not to the sea)		23	29	
PERMANENTLY SETTLED ON THE ATOLL	Less than 10 years		22	23	/
	Between 10 and 20 years		18	19	
	More than 20 years		60	57	

replies respectively), ‘coral bleaching’ (a third of responses), ‘coastal erosion’ (almost a third) and ‘coastal flooding’ (a quarter) (Table 3). If we examine the cards selected in first place only, ‘cyclones’ and ‘sea-level rise’ arrive at the same level in the ranking, just after ‘waste’. Further down the rankings, we find ‘flooding’ and ‘rising temperatures (air and/or ocean)’. If we look at the cards that were selected in second place only, ‘coral bleaching’ comes fifth in terms of priority issues. These results highlight the priority given by residents to waste, socio-economic issues (unemployment and overfishing) and health concerns (nuclear, malnutrition, mosquitoes, etc.), taking precedence over certain natural hazards such as flooding and erosion, but not over all of them (cyclone and rising sea level).

Other questions in phase 2 provided deeper insight into social perception of sea-related risks, because we asked inhabitants what, in their view, represented a ‘danger’, rather than just a ‘problem’. First of all, we see that, when asked about ‘dangers that could come from the sea or are sea-related’, 20% of the interviewees said that there wasn't any danger from the sea, or ‘I don't know’ (respectively 14.4% and 5.6%). Among the dangers cited, swell was spontaneously mentioned in first place (for 41.6%), then tsunamis (20.8%), rising sea level (18.4%), cyclones (16.8%), sharks (11.2%) and coastal erosion (4%). This order (swell, tsunamis and then cyclones (wind) was confirmed by three other questions asking interviewees to systematically select one of two proposals to answer the question: ‘which is more dangerous for the atoll?’ The responses were 1) the ‘sea’, substantially ahead of ‘wind’ (77.4% versus 54.8%), 2) ‘tsunamis’, ahead of ’cyclones' (59% versus 50%) and 3) ‘coastal erosion’, slightly ahead of ‘coastal flooding’ (59.7% versus 54%). Other questions from phase 2 confirm this mistrust of the sea and swell: 60% of respondents believe that the ‘dwellings that are best protected from the sea’ are situated ‘in the center of the atoll’, while

Table 3
The most frequently selected cards from among 20 different ‘preoccupying problems for the atoll’ (STORISK Phase 2 survey, n = 125).

Rank	Most frequently selected cards, taking positions 1 to 5 into account (as a % of resp.)		Cards most frequently selected in 1st position (as a % of resp.)		Cards most frequently selected in 2nd position (as a % of resp.)	
1	Waste	71.8	Waste	32	Waste	13.6
2	Rising sea level	44.4	Cyclone	10.4	Cyclone	12
3	Cyclone	41.9	Rising sea level	10.4	Rising sea level	9.6
4	Coral bleaching	32.3	Nuclear	8	Overfishing	7.2
5	Erosion	29.8	Unemployment	5.6	Coral bleaching	7.2
6	Malnutrition	27.4	Flooding	4.8	Malnutrition	6.4
7	Flooding	25.8	Rising temperatures (air and/or ocean)	4.8	Mosquitoes	5.6

Nota bene: List of the cards presenting possible preoccupying problems for the local people: Acidification, Climate refugees, Coral bleaching, Cyclone, Devastation, Erosion, Extractions, Flooding, Malnutrition, Mosquitoes, Nuclear, Overfishing, Rising Sea Level, Rising temperatures, Salinization, Tsunami, Unemployment, Violence, Waste, Water pollution.

53% believe that this will still be true in the future. Locations on the lagoon edge are less frequently mentioned as protected areas, even though a large share of the population lives along the lagoon on Rangiroa and Tikehau (Fig. 1). Nevertheless, given the low percentages obtained – from 44.4% for rising sea level to 29.8% and 25.8% for erosion and flooding when ranking risks (Table 3), or from 41,6% for swell to 20% for none and 4% for coastal erosion when listing potential dangers coming from the sea –, the sea-related risks appear very relative. Phase 1 confirms the overall lack of concern as 55% of the people questioned consider that they 'do not face any risks living here [on an atoll]'. Indeed, the population did not diminish after three successive cyclones in 1983, instead continuing to grow on both atolls after 1983. Finally, among the drawbacks related to life on an atoll spontaneously cited by the interviewees, sea-related risks (swell, tsunami, rising sea level) and the cyclone risk only account for 4.8% of responses. We should also add that 29% of interviewees consider that 'living on an atoll' does not come with 'any drawbacks'.

Thus the first thing we learned is that sea-related risks are not a priority issue (a danger or a risk) for inhabitants, but are however acknowledged as important, in that they are 'a problem'.

3.3. A clear perception of environmental changes over the last 70 years

In phase 2, interviewees were asked to add images to a timeline to demonstrate their awareness of the more general environmental changes that have occurred since 1950 on Rangiroa and Tikehau atolls, with regard to weather/climate, beaches and corals. While, according to half of the respondents, weather and climate events (cyclones, rising sea level, coastal flooding, floods after rain storms) could already be perceived before 1950, and even more so between 1950 and 2000, they are now perceived by a large majority (80–90% for sea swell and floods). However, the impression of 'usual weather' declined between 1950 and 2000 and the present day. In phase 1, the people questioned could also clearly remember previous natural events since 1950: when asked if they have 'ever experienced a major cyclone causing damage in their neighborhood', 23% of them referred to the storm of September 2013, 21% to the southern swell of 1996, 11% to tropical cyclone Oli in 2010 and 9% to tropical cyclone Orama in 1983. There is also clear perception of an evolution in the beaches and the barrier reef in phase 2: the number of people placing eroded beaches, sand extraction and protective groynes increased in the period up to the present day. Close to 100% of respondents placed eroded beaches on 'the present day' on the timeline, while 'healthy beaches' dropped from 90% for the period 1950–2000 to 70% for the present day. In phase 1, 80% of respondents also said that the beaches 'were (now) losing' 'a lot' or 'a bit' of sand close to where they live. On the subject of corals, the number of interviewees (phase 2) mentioning healthy corals falls off sharply from the second half of the 20th century to the present day and conversely, there is an equally marked increase in the number of interviewees mentioning coral bleaching: almost 9 out of 10 people placed the corresponding image on the timeline to indicate that it is occurring today. Similarly, we find that almost 80% of interviewees (phase 2) 'have observed' 'significant changes to the landscape in their atoll since they have lived there' (physical, anthropogenic or mixed changes). Half of them have observed physical changes (alone or combined with anthropogenic changes), most notably mentioning erosion on the lagoon side or the ocean side, and then coral bleaching. The population is also undoubtedly aware of the fact that these environmental changes have an impact on sea-related economic activities because boat fishing, fisheries and pearl cultivation, referred to by 90% of respondents for the period from 1950 to 2000, are perceived to be declining in the present day, especially boat fishing and pearl cultivation.

We can thus note a very clear perception, over an approximately 70-year period, of changes in weather and climate and a general deterioration in corals and beaches. The interviewees are clearly aware of the environmental changes that have occurred since 1950 on Rangiroa and Tikehau atolls.

3.4. A certain knowledge of climate change and its local manifestations

In phase 2, the adding of images to the timeline demonstrates that 70% of respondents expect disruptive phenomena in 2100 (cyclones, floods, coastal flooding and strong swell), while only half of all respondents expect today's 'usual weather' in that distant future. In phase 1, while not everyone questioned was able to answer on the topic of 'cyclone intensity' or the 'strength of waves' 'in the future' (respectively 43% and 47%), the respondents were nonetheless three times more likely to believe in a 'change in cyclone intensity' or 'wave strength' than not to believe in this (respectively 43% and 41% versus 14% and 12%). In phase 2, this negative forecast is even more marked for the beaches: only a quarter of respondents selected the 'healthy beach' card for 2100, while over 70% selected images showing that the beaches will be affected by rising sea levels or erosion by that date. In phase 1, 64% of interviewees considered that 'there is a risk that erosion will increase in the future', and 57% that 'the rising sea level could render parts of their village inhabitable in 60–70 years'. Changes to coral are also seen in a negative light. There is a very sharp decline in the number of respondents mentioning healthy corals in 2050 and 2100 on the timeline (20%, then even less). Naturally, coral bleaching remains a concern but with less certainty than today (85%) in 2100 (70%). Again, phase 1 confirms this negative perception of the future of coral: nearly half think that 'coral health will deteriorate in the future'. Thus a high majority of people has a negative vision of the future in both surveys, referring to an array of disruptive weather and climate phenomena, highly eroded beaches and unhealthy corals.

These outlooks go hand-in-hand with relatively good knowledge of the concept of 'climate change'. 70% of people claim to have 'heard a lot about it' in phase 1, and 90% of people to 'have heard of it' in phase 2. In addition, when the interviewees were asked for an explanation of the concept (phase 2), two thirds of them were able to indicate one or several manifestations of climate change (Table 4) and one fifth could explain one or several causes (Table 4). Only 20.8% have little or no knowledge of the concept (they are unable to respond, give inaccurate explanations or only give synonyms, with no explanation), 17.6% associate climate change with catastrophism, fear and uncertainty, and 8% did not respond (Table 4). Looking at the details, the explanations provided show that the manifestations of climate change the most frequently mentioned concern an overall rise in temperatures (a third of respondents), a specific rise in water temperatures – but not necessarily in Polynesia (a number of interviewees refer to melting ice, for example) – and rising sea levels (Table 4). Moreover, 90% of respondents think that 'their atoll could be affected by climate change in the future' (phase 2). As the main reason, 31% of respondents say that climate change is 'already visible on their own atoll' (Fig. 4), speaking, in order of importance, of a rise in temperatures (mainly air temperatures, then the ocean), a change in the seasons and, to a lesser degree, a rising sea level and coral bleaching.

Looking at the images placed on the timeline and the answers to our questions, we can conclude that the inhabitants generally have relatively good knowledge of the notion of climate change, but also of its potential effects on the local scale. However, this knowledge is not widespread: 10% of respondents consider that their atoll will not be affected by climate change in the future and 17% say that it will be affected but are unable to explain their response.

3.5. Drivers of residents' perception and profiles of residents

As mentioned above, there are economic and demographic contrasts between Rangiroa and Tikehau so we also need to ask whether social differences, a different relationship with the environment or contrasting levels of education have an impact on the responses obtained. To this end, we crossed variables from several key questions on climate change

Table 4
Order of responses to the question 'What does climate change mean to you?' (STORISK phase 2 survey, n = 125).

Response categories (5)	% of respondents [a]	Response sub-categories (19)
Manifestation(s) of climate change	66.4	1. Warmer, rise in temperatures, change in temperatures
		2. Warmer water, ice melt
		3. Rising sea level
		Changing weather, changing climate
		Changing seasons
		Change in fauna and/or flora, living conditions
		Cyclones, more wind, greater swell
		A different response, less frequently mentioned
		Change compared to the past
		Atolls: disappearance, change
		More rain, more floods due to rain
Cause(s) of climate change	20.8	Role of humans, human activity, pollution, etc.
		Greenhouse gas effect, increase in greenhouse gases, damage to the ozone layer, etc.
Little or no knowledge of climate change	20.8	Don't know
		Mistakes (tsunami, tides, overfishing, mentalities, globalization, space rockets, etc.)
		Non-specific explanations (disruption, climate change)
Catastrophism, fear, uncertainty	17.6	End of the world, grave danger, havoc, major upheaval, fear
		Refers to doubts, uncertainties, debates
Irrelevant	8	Does not respond

[a] The total percentage exceeds 100% because several responses were allowed.

asked in phase 2 of the survey (results in Table 5): 'Have you heard about climate change?' and 'What does "climate change" mean to you?'. For this specific question, each type of answer was examined as a new question: Does it mean 'catastrophism, fear or uncertainty', 'manifestations of climate change', 'little or no knowledge' or even its 'causes'? We then added two similar questions: 'Could your atoll be submerged like this (drawing 3) in 2050?' and 'Could your atoll be affected by climate change in the future?'. In this crossing of variables, one final question was: 'Would you agree to move because of climate change?'.

Initial results show that the cross-tabulation is not significant for four socio-demographic variables and these various questions. Those variables were Gender, Leisure, (professional) Occupation and Distance from the sea: the interviewees' replies do not really differ according to sex, whether or not they enjoy leisure activities related to the sea, or whether or not their occupation is related to the sea. Likewise, the fact of living near the sea (near the lagoon, ocean or a channel) rather than in the center of the island does not affect the responses. Four other variables point to a link but only with one of the dimensions. Hence, the Location variation shows that respondents on Rangiroa have heard more about climate change than those on Tikehau. The Origin variable shows that people are less likely to mention the 'causes' of climate change if they are Polynesian (compared to people from mainland France or abroad). The Age and Permanent Settlement variables give some somewhat contradictory results: the older people are, the more likely they are to associate climate change with 'catastrophism, fear or uncertainty', while this association is less frequent among people who have lived on the atoll for more than ten years. The most interesting cross-tabulations are those that show repeated links between variables and answers to the questions. For example, the Level of Urbanization variable shows that people have heard much more about climate change and mention its 'manifestations' much more when they come from the more urbanized sectors (Avatoru-Ohotu) rather than rural areas (Tikehau atoll or Tiputa island). Conversely, people in rural areas are more likely to have little or no knowledge of climate change than those in urban areas, and far more people in rural areas think that their atoll could be submerged by 2050 (drawing 3) than people in urban areas. Finally, the Education variable shows that the less well-educated people are, the less likely they are to have heard of climate change, and that people with little or no knowledge are less likely to agree to move because of its effects; they are also less likely to believe that their atoll could be affected by climate change in the future (for these four questions, this is particularly true for people with a primary school level of education).

These results were summarized in a multiple correspondence analysis (MCA) applied to phase 2 of the survey (Fig. 5). The first two axes represent 53.6% of total inertia and highlight four distinct profiles among the 95 individuals included in the MCA. Horizontal axis 1 deals with the level of education (from high school/university in the negative part to primary school in the positive part) as well as the level of urbanization (from urban-like settlements in the negative part, i.e. Avatoru-Ohutu, to more rural-like ones on the positive side, i.e. Tiputa and Tikehau). Vertical axis 2 shows people according to age and gender (female and young people above; male and older people below). The MCA highlights four distinct and interpretable groups of residents. The so-called 'informed' group accounts for 22% of those surveyed and brings together people who are familiar with the manifestations and causes of climate change and do not express any lack of awareness. They are 31–50 years old, sometimes younger, went through higher education (high school level upwards), have a sea-related profession and live in an urban-like area (Avatoru-Ohotu). Two groups of less well-informed individuals are represented on the right-hand side of Fig. 5. The so-called 'poorly informed' group account for 22% of the sample and mainly comprises Polynesian people, females, have lived on one of the studied atolls for more than ten years, went to middle high-school, take an interest in the weather and pass on their environmental knowledge to younger people. While certain individuals in this group are familiar with the impacts of climate change on their atoll (they claim to have already experienced the signs), others think that their atoll will not be affected by climate change in the future, or are unable to explain why they think that it might be. The 'uninformed' group accounts for 24% of the sample. It brings together people who have very little to no knowledge of climate change, are unfamiliar with either its manifestations or causes, live in rural-like areas (Tikehau and Tiputa), are aged over 50, only went to primary school and do not have a sea-related occupation. The last group, accounting for 26% of the sample, is made up of 'distant' people. They are usually men, of non-Polynesian origin, they have lived on the atoll for less than 10 years, they do not listen to the weather forecast and they do not pass on environmental knowledge to younger people. They have an alarmist view of climate change and expect to witness it in the future because 'they are on a low-lying atoll' and 'climate change will occur here, as elsewhere'. The MCA thus shows that respondents are divided into four groups, clearly separated by age and gender, but also by level of education and of urbanization.

Table 5
Crossing interviewees' characteristics with questions about climate change (phase 2, results in number of answers).

		Have you heard about climate change?		What does 'climate change' mean to you?								Could your atoll be submerged like this (drawing) in 2050?		Would you agree to move because of climate change?		Could your atoll be affected by climate change in the future?	
				Catastrophism, fear or uncertainty		Manifestations		Little or no knowledge		Causes							
		Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No and don't know	Yes	No	Yes	No
GENDER	Male	62	5	14	50	45	19	12	52	18	46	32	34	37	21	*55*	*4*
	Female	50	8	7	44	38	13	14	37	8	43	31	26	25	22	*34*	*8*
LEISURE	related to the sea	86	11	19	72	66	25	20	71	20	71	49	46	48	32	72	8
	not related to the sea	34	5	8	26	24	10	7	27	11	23	17	22	21	10	25	5
OCCUPATION	related to the sea	*50*	*4*	7	45	38	14	10	42	16	36	32	20	29	19	*43*	*4*
	not related to the sea	*49*	*9*	15	36	35	16	11	40	10	41	24	33	27	18	*37*	*6*
	catering	*14*	*0*	1	12	12	1	3	10	2	11	6	8	7	6	*11*	*3*
DISTANCE FROM THE SEA	Near ocean or lagoon	*56*	*10*	12	45	41	16	13	44	14	43	30	35	29	24	48	6
	Center of the islands	*43*	*3*	7	38	33	12	8	37	10	35	28	17	26	13	33	8
LOCATION	Rangiroa	**85**	**6**	16	68	63	21	16	68	*22*	*62*	41	48	47	32	*68*	*10*
	Tikehau	**27**	**7**	5	26	20	11	10	21	*4*	*27*	22	12	15	11	*21*	*2*
PERMANENTLY SETTLED	< 10 years	27	3	**9**	**18**	20	7	*4*	*23*	8	19	12	18	16	9	*22*	*3*
	> 10 years	82	10	**10**	**75**	60	25	*22*	*63*	17	68	49	41	45	32	*65*	*8*
AGE	17–30	*24*	*2*	**0**	**25**	18	7	6	19	7	18	17	9	14	7	*17*	*4*
	31–50	*51*	*7*	**10**	**41**	39	12	9	42	12	39	25	32	32	19	*42*	*3*
	50 and over	*36*	*4*	**11**	**27**	25	13	11	27	7	31	20	19	16	16	*29*	*5*
ORIGIN	Polynesian	92	13	16	80	*68*	*28*	*26*	*70*	**17**	**79**	57	47	*47*	*39*	*72*	*10*
	Other	20	0	5	14	*15*	*4*	*0*	*19*	**9**	**10**	6	13	*15*	*4*	*17*	*2*
EDUCATION LEVEL	Primary school	**17**	**5**	2	17	10	9	**11**	**8**	1	18	*11*	11	**4**	**10**	**10**	**5**
	Middle high-school & high school	**73**	**7**	13	62	57	18	**14**	**61**	17	58	42	37	**43**	**28**	**60**	**6**
	University	**21**	**0**	6	13	15	4	**0**	**19**	7	12	*8*	12	**14**	**5**	**18**	**1**
URBANIZATION LEVEL	urbanized	**69**	**3**	12	54	**53**	**13**	**8**	**58**	19	47	**29**	**41**	38	27	*54*	*8*
	rural	**43**	**10**	9	40	**30**	**19**	**18**	**31**	7	42	**34**	**19**	24	16	*35*	*4*

For numbers in normal font: the relationship between variables is not significant according to the Chi-square test. For numbers in bold: the relationship is significant according to the Chi-square test. For numbers in italics: use of the Chi-square test is not possible.

4. Discussion and conclusion

Based on the results above, we can now discuss perceptions of sea-related risks, environmental changes and climate change among the populations of Rangiroa and Tikehau from a general perspective. We will then look at the most influential drivers of such perceptions, before discussing the implications when it comes to enhancing local adaptation to climate change.

4.1. Discussion on the perceptions regarding sea-related risks, environmental changes and climate change

This first sub-section looks at why people see sea-related risks as a problem rather than a danger. This conclusion reflects Polynesian people's relationship with the ocean, as expressed by an expert in Polynesian pirogues: *'at sea, Tahitians do not conceive the word "fear". We are one of the sea's elements. (…) For a Polynesian, if the sea decides that today is your final day, that's her decision'* (in *Ouest-France* newspaper, 29/05/2017). Polynesian people do, in fact, believe that the Maohi world is part of the 'Ocean Planet' and therefore that land itself is a marine element and thus belongs entirely to the ocean (Bachimon, 1995). In Polynesian mythology, many gods are associated with the sea, some of which protect the space immediately around an atoll or fishers (Bambridge et al., 2016). There is therefore no fear to show with regard to this 'inhabited' and sacred space which forms an indivisible whole with the atolls. Such beliefs could explain why a fifth of the respondents do not associate any 'danger' with the marine world or do not know what dangers to associate with it. As for the perception of the sea-related risks mentioned, we can take the specific case of tsunamis, which one fifth of respondents cited as a 'danger', and which are seen as more important than cyclones. This apparent fear of tsunamis is all the more surprising given that the interviewees did not select tsunamis in the first seven 'preoccupying problems for the atoll' (Table 3). The difference in the responses to these two questions is probably partially linked to a general lack of knowledge about the likelihood of a tsunami occurring in this atoll region. The tsunami risk is indeed low in the Tuamotu Islands due the atolls' bathymetry, which does not comprise the kind of gentle slope a tsunami requires to develop. In addition, we see that the interviewees spontaneously mentioned the swell as the first 'danger' 'that could come from the sea or is sea-related' and selected the card showing 'a rise in sea level' as the first 'preoccupying problem', after waste (Table 3). A bias could have occurred if people actually interpreted the card on sea-level risk as showing a temporary flooding event following a strong swell – which would indicate possible confusion between the two phenomena. Indeed, R. Canavesio (2017) noted that in Eastern Tuamotu, 'temporary flooding draws much more attention from inhabitants than the rise in sea level triggered by climate change': the rise in sea level, which currently occurs at a rate of a few millimeters per year, does not appear to be visible to the population. Apart from this possible confusion between two physical phenomena (permanent vs. temporary flooding), the fact that the rising sea level is frequently mentioned in the 'preoccupying problems' could also be due to the strong influence of the media locally (see below; Worliczek, 2013).

When it comes to environmental changes, the results clearly show that the respondents have an acute and accurate perception of the environmental changes having occurred over the past seven decades, whether they concern corals and the beaches or climate and weather. Beach erosion is particularly noticeable, something that Worliczek (2013) also heard on Rangiroa around 2010. Other authors have recorded the same attention given to beach erosion in other sectors of Tuamotu: in the eastern Tuamotu Islands, F. Torrente (2017) also observed that 'coastal erosion is unanimously noticed on the lagoon side' by the people surveyed, and R. Canavesio (2017) refers to quasi-systematic beach erosion observed by the inhabitants near the villages in the five atolls of the eastern Tuamotu Islands. Here, we should note that there is nothing contradictory about choosing both the healthy beach card and the eroded beach card: firstly, both these cards were available and could be selected at the same time; secondly, both eroded and healthy beaches can currently be seen on different parts of the Rangiroa and Tikehau atolls (Duvat et al., 2017). Generally speaking, the very clear perception of environmental changes having occurred on the atolls reflects a relationship with the environment, and particularly with the natural environment, that could be described as sensory: the changes are mentioned by the inhabitants because they have actually seen them.

Our survey also shows that the atolls' inhabitants are relatively well-informed about global climate change in general. Indeed, knowledge of the causes and impacts of climate change (which we call 'manifestations' here, in Table 4) is seen as a reliable driver of perception of climate change in the literature (Van der Linden, 2015; Shi et al., 2016), especially with regard to knowledge of its causes. However, it is worth discussing what comes from general and theoretical knowledge and what really stems from local knowledge. Anthropologist E. Worliczek (2013) insists on the fact that the inhabitants of Rangiroa she spoke to in the early 2010s have heard of the concept of global climate change from TV but *'do not notice it' on their islands: for them, climate change remains imperceptible*'. Studying the eastern Tuamotu Islands in 2015, F. Torrente (2017) also points out that '*the communities met seem pretty much aware of issues related to climate change across the world (through the media and education) but find it very difficult to link those issues to local conditions*'. The influence of the media on Rangiroa and Tikehau appears to be a valid hypothesis, especially television; the main newspaper, *La Dépêche de Tahiti*, comes by plane. There are currently two general-interest television channels broadcasting to Rangiroa and Tikehau: *Polynésie Première* and *Tahiti Nui TV*, both widely viewed in Tuamotu. Since the arrival of digital terrestrial television (DTTV) in French overseas territories in 2010, the French mainland channels are also available: 70% of homes were connected to DTTV on Rangiroa and 77% on Tikehau in 2012 (ISPF, 2012 census). These TV channels are the main – if not the only – source of information about climate change on the atolls, with programs catering only for the general public, so TV-sourced knowledge plays a critical role in climate change perception and in 'the social amplification of risk' (Cologna et al., 2017; Kasperson et al., 1988). In this respect, French national authorities currently recommend periodically running educational and preventive message campaigns on the risks in local media and in partnership with the public TV channels' (recommendation no.22, Arnell et al., 2018).

Interestingly, our field survey, conducted several years after Worliczek's (2013), shows that 31.8% of interviewees declare that climate change is 'already visible on their own atoll' (Fig. 4), most notably mentioning a rise in temperatures (mainly air temperatures, then the ocean), something that people across the world are often sensitive to (Howe et al., 2012). Interviewees also report witnessing a change in the seasons and, to a lesser degree, coral bleaching. What is more, S. Van der Linden (2015) hypothesizes that '*people who have experienced extreme weather events tend to have significantly higher risk perceptions of climate change*'. Moreover, some recent events could have marked the population of both atolls, raising their local awareness of climate change, e.g. tropical cyclone Oli in 2010, and heavy rain and coral bleaching in 2016. Scientists now highlight the perception of other salient weather-related events – rather than just hot-weather-related events – such as local flooding and their role in climate change beliefs (Taylor et al., 2014), although the links between direct experience of flooding and perceptions of and response to climate change have not been systematically proven (Whitmarsh, 2008; Spence et al., 2011). Other studies have shown that the population is capable of citing specific types of global warming experienced first-hand, such as changes to seasons and to weather in general, changes to lake levels or affecting plants and animals (Akerlof et al., 2013). Hence, in addition to relatively good theoretical knowledge on global climate change in general, no doubt linked to the influence of regional and national television, we can add genuine local knowledge of climate change, something that

seems to have risen at the local level between Worliczek's survey in Rangiroa in the early 2010s and our survey in 2016–2017.

4.2. The most important drivers of climate change knowledge

We have tried to highlight potential variability in the responses obtained from the Rangiroa and Tikehau atolls and to determine the underlying drivers of local perception. To determine people's knowledge and perceptions of climate-related risks and environmental changes, it is important to examine their relationship with the local environment. This relationship not only involves experience of an event (such as a cyclone or flooding), but also everyday life and any sensitive relationship with the natural environment stemming from occupation and/or leisure activities. It also includes the distance of their home from the sea and/or the level of urbanization of the place in which they live. Hence, regular contact with environmental constraints (e.g. being surrounded by the ocean) – when you have lived on an atoll for more than 10 years – no doubt explains why climate change is less frequently associated with 'catastrophism, fear or uncertainty'. However, our analysis shows that neither closeness to the sea nor a sea-related occupation or leisure activity substantially affects knowledge and perceptions in Rangiroa and Tikehau, where we could have expected the interviewees who are regularly in contact with the sea in one way or another to be more sensitive to their environment and able to mention some of the manifestations of climate change, at least those concerning the sea (Fig. 4). Considering that the distance between home and the sea does not appear to be a critical determine of sea-related risk perception, one reason could be the narrow breadth of the islands (Fig. 1), which means that inhabitants are never very far from the sea, regardless of where their dwelling is located. Another reason could be the fact that sea-related hazards are not precisely localized on an atoll and that it is more difficult to perceive a risk which has its sources in an uncertain location (Glatron et Beck, 2008). Two factors can explain the weak influence of the relationship with the sea. On the one hand, the proportion of people involved in a sea-related profession and therefore potentially able to observe coastal/ocean environment changes over the long term has gradually fallen. Hence, in our samples, 56–75% of respondents now work in a profession unrelated to the sea and in the tertiary sector (shops, healthcare, maintenance, administration, education, etc.). Among them, only the 11% who work in agriculture (phase 2) remain more in contact with their environment. There has also been a transition from a traditional lifestyle to a more western lifestyle. In other words, lifestyles have shifted towards jobs in the tertiary sector and indoor leisure pursuits, while '*previous generations* [of Rangiroa] *spent time outdoors, in contact with nature and in phase with the cycles of the natural physical environment*' (Worliczek, 2013). This general shift in Polynesian society also explains why the Gender and Origin drivers no longer mark any differences between the answers from men and women or from Polynesians and non-Polynesians. On the other hand, we should not forget that, although the drivers concerned with the relationship with the marine environment (location, occupation, leisure) no longer enable us to distinguish between the various inhabitants' perceptions, this relationship with the environment has not completely disappeared: our results show that perception of environmental changes over the last 70 years generally remains high on Rangiroa and Tikehau.

The statistical analysis also suggests that the Urbanization level variable is more discriminatory than specific location on one of the atolls (the Location variable): we are more likely to have heard about climate change and more likely to mention its 'manifestations' in more urbanized sectors (Avatoru-Ohotu) than in rural areas (Tiputa island or Tikehau atoll), whereas people in rural areas are more likely to have little or no knowledge of climate change and more likely to think that their atoll could be submerged by 2050 (drawing 3). In rural areas, living conditions differ enough to trigger other perceptions. The inhabitants' educational level is lower on Tikehau than on Rangiroa: 43.8% of people aged 15 and over do not have any qualification, compared to 33.6% on Rangiroa, and only 31.4% have a qualification higher than CAP-BEP level (high school level at 17 years of age) compared to 34.7% on Rangiroa (ISPF, 2012 census). In addition, in Tikehau and Tiputa, it appears more difficult to access sources of information on climate change (other than television) than on Rangiroa. Also, non-Polynesians more inclined to refer to this information are less likely to live in rural areas: in 2012, there were eight non-Polynesians living on Tikehau, compared to 128 on Rangiroa (ISPF, 2012 census). In addition, the tertiary professions involving greater openness to information are less well developed in rural areas: there are fewer shops, administrative services, healthcare services and links with the education system on Tikehau than on Rangiroa. Finally, there is less access to the internet on Tikehau where 27.3% of homes are connected to the internet, compared to 31.2% on Rangiroa (ISPF, 2012 census). Such disparities are set to increase as Rangiroa, along with ten other islands in French Polynesia, will benefit from the deployment of the Natitua submarine cable from Tahiti in autumn 2018, bringing very fast internet speeds.[2] As for the fact that rural dwellers are more likely to believe that their atoll could be submerged by 2050, this could be due to the very strong influence of the general-interest media (which tend to show atoll submergence as a widespread, alarming phenomenon), with little or no counterbalancing from other information sources.

The statistical analysis suggests that the education system now plays a key role in intellectualizing knowledge about climate change, at least after middle high-school level. In actual fact, in their drawings showing their atoll in 40 years' time, teenagers still at middle high-school (11–12 to 14–15 years old) make very little reference to topics such as the disappearance of the atolls due to rising sea levels, sea-related risks or other effects of climate change on atolls. They more frequently mention modernization or development of their atoll, the destruction of nature or pollution (Goeldner-Gianella, 2018). This calls for better inclusion of information campaigns focused on climate change in primary and middle high-school curricula, which currently reflect more national concerns (i.e. those affecting France at large) than the specificities of a highly marine context (Ghasarian et al., 2004). This would help to raise awareness about local climate change-related threats among young people and, together with continued information on the anthropogenic drivers of risk (e.g. settlements in risk-prone areas, badly calibrated coastal defenses, etc.), about possible responses for adapting to climate change. Other studies dealing with non-atoll contexts show that education is a critical driver in the understanding of climate change and sea-related hazards: in their study of 119 countries, Lee et al. (2015) conclude that '*educational attainment is the single strongest predictor of climate change awareness*'. Pruneau et al. (2008) study how far educational systems can contribute to raising standards in climate change awareness and Shi et al. (2016) emphasize the importance of educating populations in the causes of climate change to raise their awareness of the issue. In the Tuamotu Archipelago, however, people who continue their studies to high school and university level have to leave the atolls and go to Tahiti where all these educational institutions are located, or to mainland France some 15,000 km away. There, they often adopt an urban way of life, become somewhat subject to acculturation and spend several years away with no sensitive relationship with their home environment. This could influence some changes in their perceptions of local risks. On the other hand, these young people acquire some keys to a more scientific understanding of climate change and environmental changes, and therefore come to represent a kind of paradox where their improved intellectual knowledge of global climate change in general is opposed to a less sensitive relationship with their native environment. This is reflected in the MCA results where, on the one hand, the 'poorly informed' or 'uninformed' profiles claim to have already 'seen' the

[2] https://www.lantenne.com/Avec-le-cable-sous-marin-Natitua-la-Polynesie-plonge-dans-l-ere-du-numerique_a43661.html.

effects of climate change on their islands, pass on their knowledge of the environment and pay substantial attention to the weather, while the 'informed' profiles demonstrate more cognitive knowledge of climate change and its causes in particular.

4.3. Implications for adaptation to climate change

The survey shows that most of the interviewees are relatively keen observers of the landscape and contemporary changes to it, even though the relationship to the marine environment tends to decrease progressively from one generation to another on both atolls studied. People report a clear perception of changes having occurred to the weather and climate and to coral reefs and beaches over the last 70 years; most of them also expect continued changes due to climate change. These results are fully consistent with the work done by Ghasarian et al. (2004) on the type of knowledge demonstrated by Polynesians: *'The* maòhi *language combines the notions of "see" and "know" in just one word* – ìte –, *to produce a single vision of what knowledge is. (…) It is as if knowledge is first and foremost perceptive and sensitive, based on physical experience (or close-up experience, where co-presence is more important than the distant) –, which we can call* a sensitive knowledge' set (translated from Ghasarian et al., 2004). This kind of 'sensitive' perception plays an important role in risk awareness as, in line with Van der Linden's (2015) conclusions about the importance of enhancing experiential factors of climate change compared to cognitive factors, it is certainly easier to raise risk awareness on the basis of sensitive perception than on purely intellectual knowledge. Carlton and Jacobson (2013) also hypothesize that we would communicate more effectively by focusing on physical environment risk, especially salient and understandable risks, rather than talking about general impacts of climate change. This leads us to confirm that in French Polynesia, at least in the Tuamotu Archipelago, supporting the development of an existing – although sometimes declining – sensitive perception of climate change is critical in supporting the adaptation process. This is all the more challenging today given that, again, the interviewees who went on to higher education (high school and sometimes university) are increasingly concerned with a more *cognitive set of knowledge* (Ghasarian et al., 2004), more compliant with the western culture of mainland France, and therefore more disconnected with the local reality of atoll contexts. The chi-squared tests (Table 5) and the four profiles described above (Fig. 5) show this kind of sensitive/cognitive disconnection. A major challenge in French Polynesia thus consists in bringing the sensitive and intellectual dimensions closer together. This could most notably be achieved by better integrating context-specific risks related to climate change into school curricula from middle high-school onwards. This is already the case in some of the French Overseas Territories, for example in the French West Indies (Caribbean), Reunion Island (southwestern Indian ocean) and New Caledonia (Western Pacific), where the chapter '*Habiter les littoraux*' (= Living in coastal areas) studied in the first year of *collège* (middle high-school, 11–12 years old) reflects local considerations in terms of how to adapt to climate change. This is missing from French Polynesia's curricula, which is surprising given that it is acknowledged across the world that atolls are at the frontline of climate change (Nurse et al., 2014; McLean and Kench, 2015). In addition, it would be extremely valuable to define an ambitious 'cultural and environmental' policy to help young people forced to leave their atoll for educational purposes maintain contact with their home environment and with Traditional Ecological Knowledge (TEK). Only on these conditions can education be expected to help reduce the gap between sensitive and cognitive sets of knowledge.

More generally, to reduce the discrepancies in sea-related risks and climate change perceptions between inhabitants, and between urban and rural atolls, various sources of knowledge should be better combined, with western-based sources on the one hand, and traditional and indigenous on the other, as advocated by the new theoretical approach known as 'Nature's Contributions to People' (NCP) (Diaz et al., 2018), which is worth applying to the issue of climate change and the related risks. It is worth noting that there is progress is some areas, such as the *Climate and Energy Plan for French Polynesia (2015–2020)* which, in its 20th *fiche-action,* emphasizes the need to take stock of, enhance and disseminate traditional lifestyles and practices that can help with adaptation to climate change. Similarly, the *General Development Plan for French Polynesia* (Ministère du logement et al., 2017) considers that Tuamotu faces the challenge of 'renaturing the shoreline, restoring detrital coastal deposits and limiting the removal of natural materials from land or sea' within 20 years, in order to restore protective practices of the past. Finally, the recommendations in the latest report on natural risks in French overseas territories (Arnell et al., 2018) insist on the need to systematically run annual full-scale drills to develop sound acculturation of natural risks among the population (recommendation no.23) – alongside more conventional methods such as information campaigns and initiatives in schools and businesses (recommendation no.19). The results of our study fully support such recommendations on local tradition-based measures in a context where TEK still exists. Nonetheless, in rural areas and among the older or less education population groups, it is also essential to establish an official link between reviving these traditional practices and the aim of offsetting the impacts of climate change, the concept of which also needs to be better explained.

Declarations of interest

None.

Contributors

LGG: Phase 2 survey's conception and survey in the field. Phase 1 and 2 surveys' analysis, manuscript's redaction and corrections. DG: Phase 2 survey's conception and survey in the field, statistical MCA. AKM: leader of the phase 1 survey, manuscript's redaction. EB: Phase 2 survey in the field. VKED: leader of the STORISK's program and of the Phase 1 survey. All authors read and approved the final manuscript.

Financial support

The "STORISK Project" research programme is supported by the French National Research Agency under the Grant N° ANR-15-CE03-0003. AKM also thanks the French Government for its support under the "Investissement d'avenir" program, managed by the French National Research Agency (ANR-10-LABX-14-01).

Acknowledgements

Our thanks go to the organisations that have provided us with advice or support (political and religious staff of the atolls) and to the numerous anonymous inhabitants who answered our questions. The authors thank the Masters' students Fanny Rubia, Adrien Prenveille and Julie Delannoy for contributing to the generation of the survey's data on Rangiroa and Tikehau, and the student Léa Thorel for her participation in the editing of the manuscript. We also thank the three anonymous reviewers for their comments.

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